# An Literature Review On Welding Of Titanium Alloys With Steels Using Friction Stir Welding

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***Abstract***- *Welding of dissimilar metals is the one of important challenges in past, but now it was kick out by Friction welding, and it is the only process used for welding dissimilar metals. It is ordinarily welding process in industries like automobile industries, submarine engineering industries aeronautical industries, and heavy duty industries. High strength titanium alloys are of interest for structures requiring minimum weight, especially in the aerospace industry. Along with the interest in high strength alloys, there is a growing requirement to join titanium alloy components In this research paper, review of research papers related to welding of titanium alloys with other metal and its alloys is done.*

***Keywords***- Friction welding, Dissimilar metals, Titanium alloys.

## I. INTRODUCTION

Friction welding is a type of solid state or simply forge welding, where welding takes place by the application of friction between two mating surfaces of metal along with application of pressure. Required heat can be generated by rubbing two metals on each other and the temperature can be elevated to the level where the parts subjected to the friction may be welded together. Friction Welding is a collection of solid state welding processes, where heat is produced by means of mechanical friction between moving and stationary work pieces with the addition of an upsetting force to displace material plastically.

### TYPES OF FRICTION WELDING

1.1 LINEAR FRICTION WELDING
1.2 ROTARY FRICTION WELDING
1.3 INERTIA FRICTION WELDING
1.4 FRICTION SURFACING
1.5 FRICTION STIR WELDING

### 1.1 LINEAR FRICTION WELDING

Linear friction welding (Fig. 1) is so named because the relative motion across the interface is linear, rather than rotary. It is a process of producing high integrity welds with non-melting fusion & little prior surface preparation.

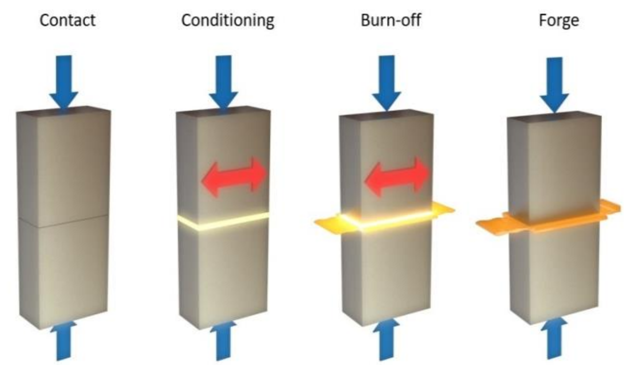


FIG. 1 LINEAR FRICTION WELDING

### 1.2 ROTARY FRICTION WELDING

Rotary friction welding (Fig. 2) is a type of fiction welding in which one component is rotated against the other, is the most commonly used among the friction welding processes.

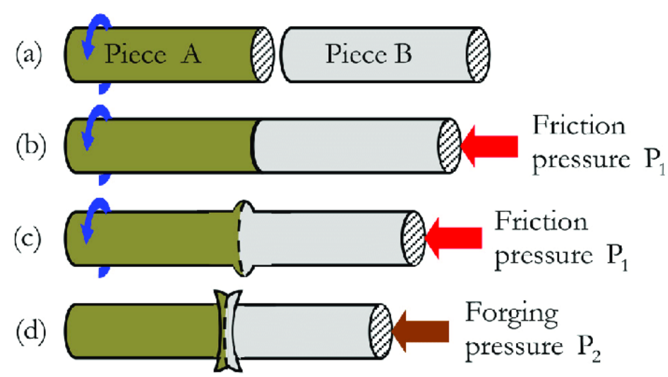


**FIG.2 ROTARY FRICTION WELDING**

### 1.3 INERTIA FRICTION WELDING

In Inertia Welding (Fig. 3), one of the work pieces is connected to a flywheel and the other held stationary. The flywheel is rotated to a fixed rotational rpm, storing the required kinetic energy. The drive is then disconnected and the work pieces are forced together by the friction welding force. This causes the contacting surfaces to rub together under pressure. Due to which kinetic energy stored in the rotating flywheel generates heat through friction at the weld interface as the speed of flywheel decreases. Then force to generate friction welding may be applied before rotation stops. The force is retained for a fixed time after rotation stops.

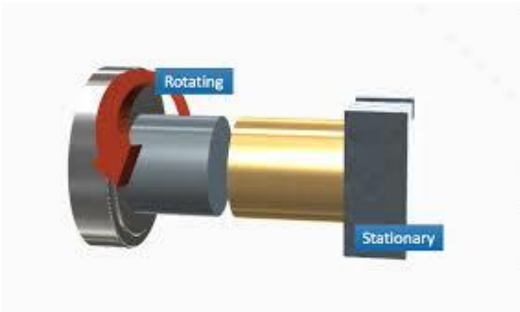


**FIG.3 INERTIA FRICTION WELDING**

### 1.4 FRICTION SURFACING

It is the type of friction welding (Fig. 4) where a layer of coating material is coated on a work piece. Coating material is in the form of rod which is rubbed under pressure on to surface of work piece to form coating. By moving a workpiece against the face of the rotating rod a plasticized layer of 0.2 to 2.5 mm thick is deposited. This results in creation of composite material demanded by any given application

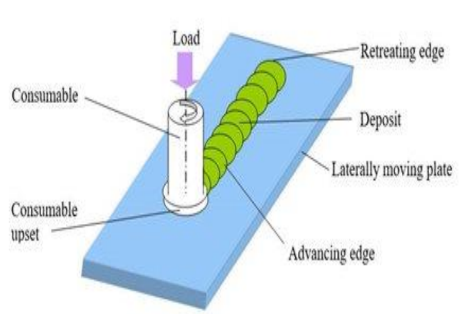


**FIG.4 FRICTION SURFACING**

### 1.5 Friction stir welding

Friction stir welding also produces a required plasticized state of material, but in a different way. A non-consumable rotating tool is held under pressure against the materials to be welded. This tool is like a pin at the center, or probe, followed by the shoulder (Fig. 5). A plastic state material is generated due the heat resulted from friction between tool & materials it is in contact with. As the tool moves along the joint line, material from the front of the tool is cleaned around this plasticized circular region to the rear, so reducing the interface.

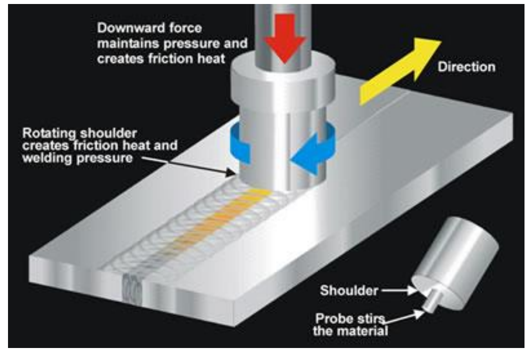


**FIG.5 FRICTION STIR WELDING**

### 1.6 ADVATAGES

- Weld heat affected zone (HAZ) has a fine grain hot-worked structure, not a cast
- structure found with conventional welding
- Material and machining cost savings
- 100% Bond of full cross section
- No fume is produced
- No porosity
- No spatter
- No filler wire is required for welding

### 1.7 DISADVANTAGES

The disadvantage of friction welding are that not every configuration is feasible,that a machine of sufficient power is needed and that for short runs the process may not be economical.

Apart from the cost of equipment ,which must be suitable for the intended joints,the friction welding process has some costs in tooling and set up that must be taken into account when calculating the costs per weld.Tight cocentricity requirements,when needed,may be difficult to meet. Also finishing operations may be requested which sum up to the total cost.

### 1.8 APPLICATION

Friction-welded applications span the aerospace, agricultural, automotive, defense, marine, and oil industries

Friction welding is used for everything from tong-holds on forging billets to critical components of aircraft engines.

- Some of the automotive parts manufactured by friction welding include gears, engine valves, axle tubes, driveline components, strut rods and shock absorbers. Manufacturers of agricultural equipment commonly use friction welding to fabricate hydraulic piston rods, track rollers, gears, bushings, axles and similar components.

- Friction-welded aluminum-to-copper joints are in wide usage in the electrical industry.
- Stainless steels are welded to carbon steels in various sizes to make components for marine drive systems and to manufacture water pumps for residential and industrial use.
- Friction-welded assemblies often are used to replace expensive castings and forgings.

## II. FSW OF TITANIUM ALLOYS

The majority of common titanium alloys are generally weldable by conventional means, problems with workpiece distortion, and poor weld quality, can occur. In addition, some of the more advanced titanium alloys (such as Ti-6246 and Ti-17) can be difficult to weld by fusion processes. The development of FSW offers the possibility of a new, cost effective, method of producing high quality, low distortion, welds in Ti sheet and plate

Grain structure evolution during FSW of commercial purity α – titanium with Mo based alloy tool has been studied using optical microscopy and electron back scattered diffraction (EBSD). The grain structure evolution was shown to be a complex process driven mainly by the texture induced grain convergence, but also involving the geometrical effects of strain and limited discontinuous recrystallization. The development of the deformation induced grain boundaries in the stir zone was demonstrated to be influenced by texture evolution. TC4 titanium alloy was friction stir welded using W-Re pin tool. The micro structural observation made in the stir zone revealed equaled recrystallized α phase, transformed β phase and fine lamellar α + β. The stir zone was considered to be weakest part of joint and fracture surface reveals a typical plastic fracture characteristic. Development of given structure during high temperature β phase field during FSW of Ti-6Al-4V alloy has been studied. EBDS analysis confirms that β to α phase transformation during the cooling cycle of FSW was governed by Burger's orientation relationship. It also indicates that material flow in the β phase field resulted from a simple shear deformation arising from the {110} <111> slips. FSW is carried out in Ti-6Al-4V by adding 0.3 and 0.5 wt% of hydrogen (HYDROGENATION). This results in widening the welding parameters like rotation speed and traverse speed. It improves weld appearance, tool life and also reduces flash significantly. The microstructure in as received material Ti-6Al-4V consists of primary α and transformed β. Titanium alloys have a high affinity for hydrogen. It is demonstrated as temporary alloying element during FSW and then removed through a subsequent post weld dehydrogenation process. FSW with hydrogen in titanium Ti-6Al-4V alloy reveals a microstructure of acicular martensite in as weldeded structure which is related to reduction of critical cooling for martensite transformation. After post weld dehydrogenation process, martensite gets transformed into α + β which is fine equiaxed microstructure in weld zone. The addition of hydrogen is very effective in reducing softening temperature, thereby improving hot workability of titanium alloys and flow stress. An Finite element method (FEM) for FSW of Ti-6Al-4V titanium alloy has been developed to predict the phase volume fraction in typical weld zones and compared with the experimental procedures. The model result reveals that with increase in rotational speed of the tool from 300 to 700 rpm, the microstructure changes from α phase to α + β phase in the stir zone. It is also stated that the final phase volume distributions are in good agreement with experimental observations. Tool wear characterization has been studied by weight loss method, pin profile photographic technique and microscopic observations during FSW of titanium alloy Ti-6Al-4V the tool materials taken for study are W-La2O3, CY16 grade WC-Co and WC411 grade WC-Co tools. It is reported that tool deformation is observed in W-La2O3 with small conical pin which can be overcome by increasing the size of conical pin. Fracture was observed in CY16 grade WC-Co tool with 8% wt Co. No fracture or deformation is observed in WC411 grade WC-Co tool with 115 wt Co.

### 2.1 MATERIAL SELECTIION

Titanium is an allotropic metal that exhibits high specific strength, mechanical properties, excellent corrosion resistance and concurrent weight. Due to their excellent properties, titanium is widely applied in the fields of aerospace, automotive, shipbuilding, railways, medical transplants etc. Titanium has hexagonal close packed crystal structure (HCP) with limited number of independent slips which can't accommodate arbitrary plastic strain. On alloying titanium with elements like aluminum, tin, vanadium, molybdenum, chromium, copper, zirconium, silicon either crystal can be stabilized, forming alpha, beta and mixed alpha beta titanium. These three types of titanium have its own advantages and limitations but mixed alpha beta is considered as metallurgicaly balanced due to presence of both alpha and beta stabilizers. These mixed alpha and beta have range of applications especially Ti-6Al4V titanium alloy is extensively used in various applications. Pure titanium and alloys of titanium with alpha stabilizing elements maintain the crystal structure HCP and they are called alpha titanium grades. These grades don't exhibit ductile –brittle transformation and hence finds its applications in cryogenic temperature. The beta titanium alloys contains beta stabilizing element and small amount of alpha stabilizers which allow second level phase strengthening. The major alloying element is considered to be very biocompatible, which brings beta titanium alloys to have applications related to medical transplants. These possess good fabricability. But total worldwide output of titanium mill products includes only a few percent of beta titanium alloys by weight. Welding of titanium alloys are done by traditional fusion welding techniques like gas tungsten arc welding (GTAW), Gas metal arc welding (GMAW), plasma arc welding, Laser beam welding etc. These techniques have several difficulties due to high material reactivity with oxygen, hydrogen, nitrogen with consequent embrittlement of the joint. The below are the summary of recent works in titanium based alloys using FSW.

## III. OBJECTIVES OF THE REVIEW

Following are the objectives of the literature review.

a) To study work done in the area of friction welding by different researchers.
b) To study their findings.
c) To identify the research issues

Sahin et al., [1] have studied friction welding of plastically deformed steel bars. They worked on continuous drive friction welding of same material but different diameters bars. They used carburizing steel for that purpose.

Mumin Sahin, [2] have worked on computer program simulation of how weld flashes occur in welded joints of equal or different diameter of AISI 1040 (Medium carbon steel). He investigated that the optimum welding parameters obtained from equal diameter parts cannot be used in welding of parts that have different diameter and width. As a result, in welding of parts having different diameter and width, the optimum parameters of the joints should be ordinary selected in the experiments. Mumin Sahin,

[3] have worked on friction welding of high speed steel (HSS—S 6-5-2) and medium carbon steel (AISI 1040) (both of 10 mm dia.). He investigated optimum welding parameters for these combinations of metals. Also, he finds that the tensile strength of welded part is close to that of medium carbon steel (AISI 1040).i. e. the part having weaked of medium carbon steel (AISI 1040).

Satyanarayana et al., [4] have carried out a study on continuous drive friction welding of austeniticferritic stainless steel. The parent metal used for that study was AISI 304 austenitic stainless steel and AISI 430 ferritic stainless steel. He used ANOVA technic of Yate’s algorithm to analyze the results obtained by experiments.

Meshram et al., [5] conducted an investigation of dissimilar metal joining combinations: Cu–Ni, Fe– Cu, Fe–Ti, Cu–Ni Fe–Ni and Cu–Ti. They observed the influence of interaction time on microstructure and tensile properties of the friction welding of five dissimilar metal combinations.

Moat et al., [6] have studied Microstructural variation across inertia friction welded SCMV (high strength low alloy Cr–Mo steel) and Aermet 100 (ultra-high strength secondary hardening steel). They carried out micro-hardness testing and hard X-ray diffraction mapping on inertia friction welded samples of SCMV steel and super high strength Aermet 100 steel in the as-welded postweld heat-treated condition.

Dey et al. [7] chose titanium (18 mm dia. & 100 mm length) and 304L stainless (14 mm dia. & 100 mm length) steel to weld by continuous drive friction welding. During this work they have investigated optimum friction welding parameters that produce joints that are stronger than the Ti base material as confirmed by tensile test, and tensile test failure occurred in the Ti base material. As-welded bend test samples failed with almost zero bend ductility. The bend ductility was improved to 5° PWHT (Post weld heat treatment). Corrosion test showed corrosion rate of 10 mpy (milli-inch per year) with boiling nitric acid.

Seli et al., [8] have studied mechanical properties of mild steel and aluminum welded rods to understand the thermal effects. They used an explicit one-dimensional finite difference method to approximate the heating and cooling temperature distribution of the joint. They observed thermal effects of the friction welding to have lowered the welded materials hardness compared to the parent materials.

Winiczenko et al., [9] have investigated friction welding of ductile iron with stainless steel (both 20 mm dia. & 100 mm length). They used stainless steel interlayer in two ductile iron bars to weld it by continuous drive friction welding.

Udayakumar et al., [10] have carried out experimental investigation of mechanical and metallurgical properties of super duplex stainless steel bars welded by friction welding. They carried experiments on specimens of super austenitic stainless steel (UNS S32760) of 16 mm diameters and 100 mm length. A four factor, three level central composite designs (CCD) was used to determine optimal factors of friction welding process of super duplex stainless steel.

Sivajikarna et al., [11] had work on the literature review on the searched of the tool materials which have high strength,wear resistance and cost effective using tungsten based alloy tools, cobalt based tools and molybdenum based tool and poly crystalline cubic boron nitride tools

M. Avinesh et al., [12] had studied Ti-6Al-4v similar metal joints and on the interesting development of microstructure and properties have been found the HAZ is very narrow and not non-existant in the case of 1500 and 2000 RPM specimens

Vivek C M et al., [13] FSW carried out in similar metal and in dissimilar metal carried out aluminium titanium alloys and magnesium of hydrogenation, beta titanium optimization of the optimization of the welding parameters can made using various well established techniques based on the clutch area

Kim et al., [14] reported that WC-Co is generally classified into two grades. One of the grades is straight grades also referred to as unalloyed grades. These are pure WC-Co composites. For cutting tool grades, they contain between 3-13 wt% (weight percent) Co. Straight grades are the most wear resistant of the two grades. The other grade is known as alloyed grades. These have a composition of 3-12 wt% Co, 2-8 wt% TiC, 2-8 wt% TaC, and 1-5 wt% NbC. These are used on harder materials like steel

Liu et al. [15] noticed that although WC-Co is a hard material, it can still wear out under certain welding conditions. In a study which they conducted a WC–Co tool was used in friction stir welding of a cast (AC4A Al–Si alloy matrix) aluminium metalmatric composite.

Yingping J et al., [16] The micro-structural evolution, micro-hardness, tensile properties and impact toughness of LFW dissimilar welds with Ti64 and Ti17 alloys were investigated.

K.Szymlek et al., [17] Review of titanium and steel welding methods including friction welding strength parameters advantages of joining of X10CrNiTi189 steel with copper, 2) joining of titanium with vanadium, 3) joining of titanium – vanadium elements with elements composed of copper - austenitic steel.

## IV. RESULT

I have planned to study the dissimilar welding of Ti-6Al-4V alloy with Duplex stainless steel (32205) by both rotary friction and friction stir methods at different parameters and find out the mechanical and micro structural properties of the alloys at each method and by this process find the optimum parameters and the best method to weld them. This is process has not been tried before for this alloy combination and I'm trying to find a suitable method to weld them.

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